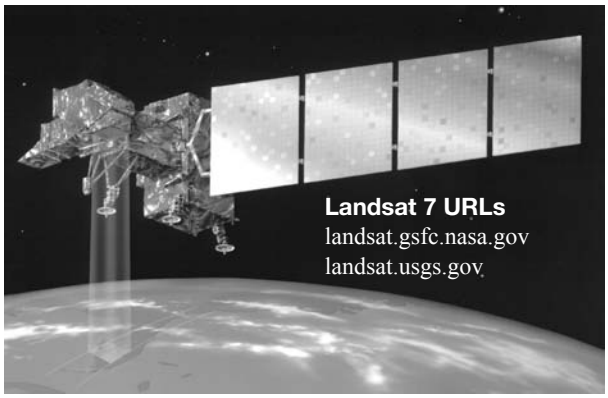
Landsat 7



Summary

July 23, 2002, was the 30th anniversary of the launch of the first of a series of Landsat satellites that have continuously supplied the world with global land surface images. Landsat 5, launched in 1984, continues to provide important observations of the landmass of the planet and has established a record for reliability in the civilian satellite fleet. Landsat 7 joined Landsat 5 in April 1999. Both Landsat 5 and Landsat 7 provide data for remote sensing and Geographic Information System (GIS) science and applications around the world. NASA was responsible for the development and launch of Landsat 7 and the development of the ground system. USGS is responsible for operating the satellite, distributing the data, and maintaining an archive of Landsat 7 and other remotely sensed data.

Instrument

- Enhanced Thematic Mapper Plus (ETM+)

Points of Contact

- *Project Scientist:* Darrel Williams, NASA Goddard Space Flight Center
- *Deputy Project Scientist:* James Irons, NASA Goddard Space Flight Center

Other Key Personnel

- *Landsat 7 Program Scientist:* Garik Gutman, NASA Headquarters
- *Landsat 7 Program Executive:* Lou Schuster, NASA Headquarters

Mission Type

Earth Observing System (EOS) Systematic Measurements

Key Landsat 7 Facts

Joint with U.S. Geological Survey (USGS)

Heritage: Landsat 4, 5

Orbit:

Type: Circular, sun-synchronous
Equatorial Crossing: 10:00 a.m. ± 15 mins
Altitude: 705 km ± 5 km (at the equator)
Inclination: 98.2° ± 0.15°
Period: 98.9 min
Repeat cycle: 16 days/233 orbits

Dimensions: 4 m high, 2.7 m diameter

Mass: 1982 kg

Power: 1550 W

Downlink: Three 150 Mbps wideband downlinks

Antennas: 3 gimbaled X-band, 2 omni S-band

Design Life: 5 years

Partners

Spacecraft: Lockheed Martin

ETM+: Raytheon Santa Barbara Remote Sensing

Data Archival, Processing, Ground Operations: USGS National Center for Earth Resources Observation System (EROS) data center

Spacecraft and Sensor Maintenance: NASA GSFC

Calibration: EROS and GSFC

Launch

- *Date and Location:* April 15, 1999, from Vandenberg Air Force Base, California
- *Vehicle:* Delta II

Relevant Science Focus Areas

(see NASA's Earth Science Program section)

- Carbon Cycle, Ecosystems, and Biogeochemistry
- Earth Surface and Interior

Related Applications

(see Applied Sciences Program section)

- Agricultural Efficiency
- Air Quality
- Aviation
- Carbon Management
- Coastal Management
- Disaster Management
- Ecological Forecasting
- Energy Management
- Homeland Security
- Invasive Species
- Public Health
- Water Management

Landsat 7 Science Goals

- Acquire sunlit, essentially cloud-free global seasonal coverage of Earth's land masses.
- Provide well-calibrated radiometric and geometric data.
- Provide imagery that are sufficiently consistent in terms of acquisition geometry, spatial resolution, spectral characteristics, and calibration with previous Landsat data to meet requirements for global-change research.

Landsat Chronology

The first Landsat, originally named the Earth Resources Technology Satellite (ERTS-1), was developed by NASA and launched in July 1972. Subsequent first generation Landsat launches occurred in January 1975 and March 1978. In the meantime, a second generation of Landsat satellites was developed. Landsat 4 was launched in July 1982 and Landsat 5 in March 1984. Images are still being received from Landsat 5. As a result, a continuous set of Landsat remotely sensed images of Earth's land surface and surrounding coastal regions from mid-1972 until the present is available.

Over the past 32 years, scientists have developed a wide range of applications using Landsat imagery for global-change research, regional environmental studies, national security, and other civilian and commercial purposes. For example, Landsat images have been used to monitor agricultural productivity, urban growth, and land-cover change, and are used widely for oil, gas, and mineral exploration. Other science applications include monitoring volcanoes, glacier dynamics, forestation/deforestation, and coastal conditions.

Authorized by Public Law 102-555 in October 1992, Landsat 7 continues the long-standing Landsat tradition. The science mission of Landsat 7 is targeted to regional and global assessments of land-cover dynamics. The mission has generated and is periodically refreshing a global archive with substantially cloud-free, sunlit imagery. For the first time, a Long-Term Acquisition Plan was devised to ensure maximal global data acquisition, taking into account vegetation seasonality and cloud cover. This ensures a data archive recording the full seasonal and interannual changes in the vegetation patterns of the planet, while minimizing the effects of cloud cover. In addition, the seasonal requirements of various science-community niches such as reefs and glaciers have been incorporated into the acquisition plan.

While NASA's other EOS instruments, like the Moderate Resolution Imaging Spectroradiometer (MODIS) and Multi-Angle Imaging SpectroRadiometer (MISR), acquire frequent, coarser views of land-cover change, the higher spatial resolution of ETM+ data from Landsat 7 allows researchers to determine the actual causes of observed land-cover changes. These changes have important implications, both for local habitability and for the global cycling of carbon, nitrogen, and water.

In 1994, management of the Landsat Program was assigned jointly to NASA, NOAA, and the USGS. In March 1999, this management structure was streamlined to include NASA and USGS only. NASA was responsible for the development and launch of

Key ETM+ Facts

Instrument Type: Imaging radiometer

Scan Type: Whiskbroom scanning radiometer

Calibration: Full-aperture solar calibrator, partial-aperture solar calibrator, internal calibration lamps for reflective bands; blackbody source for thermal band

Field of View (FOV): ±7.5°; 183 km

Instrument Instantaneous FOV (IFOV):
Bands 1–5, 7: 42.5 ±4.3 µrad
Panchromatic Band (8):
19.5 µrad × 21.5 µrad
Thermal Band (6): 85.0 ±9 µrad

Swath: 183 km, ±7.5°

Repeat Cycle: 16-day

Spectral Range and Spatial Resolution:

7 reflective spectral bands, including:
- Three 30 m visible (VIS) bands
- One 30 m near infrared (NIR) band
- Two 30 m shortwave infrared (SWIR) bands
- One 15 m panchromatic (PAN) band
- One emissive 60 m thermal infrared (TIR) band

Dimensions:
Scanner Assembly: 196 cm × 114 cm × 66 cm
Auxiliary Electronics: 90 cm × 66 cm × 35 cm

Mass: 425 kg

Power: 590 W (imaging), 175 W (standby)

Duty Cycle:
16.7% imaging over 23 hours
131 min within 600 min sliding window
52 min within 200 min sliding window
34 min within 100 min sliding window
15 min night imaging per orbit

Data Rate: 150 Mbps over two 75-Mbps channels (I and Q)

Thermal Control: 90 K radiative cooler

Real-time Data: Yes

Date of Initial Data Acquisition:
April 18, 1999 (all data prior to June 29, 1999 are engineering data; science data are available starting June 29, 1999, when the ETM+ was declared operational)

the Landsat 7 satellite and the development of the ground system. USGS is responsible for operating the satellite, distributing the data, and maintaining an archive of Landsat 7 and other remotely sensed data.

With Landsat 5 recently surpassing 20 years of continuous operation on orbit, Landsat 7 provides much-needed continuation of land remote-sensing data critical to understanding environmental change and supports a broad range of other important Earth science and Earth resource applications.

Landsat 7 Program Objectives

- Maintain Landsat data continuity by providing imagery that is consistent in terms of acquisition geometry, spatial resolution, calibration, coverage characteristics, and spectral characteristics, and calibration with previous Landsat imagery.

- Generate and periodically refresh a global archive of substantially cloud-free sunlit land-mass imagery.

- Continue to make Landsat-type data available to U.S. and international users at the cost of fulfilling user requests, and expand the use of such data for global-change research and commercial purposes.

Landsat 7 Flight Segment

The Landsat 7 satellite consists of a spacecraft bus and a single instrument, the Enhanced Thematic Mapper Plus (ETM+). Like its predecessors, Landsat 7 produces Landsat scenes based on the Worldwide Reference System, consisting of 57,784 scenes, each 183 km × 170 km. Approximately 15,000 of these cover the land-mass, coastal and island scenes of the world that are emphasized in the Long-Term Acquisition Plan developed for Landsat 7. The Landsat 7 satellite operates in a circular, sun-synchronous orbit with an inclination of 98.2°, an altitude of 705 km, and a descending-node equatorial crossing time of 10:00 a.m. ±15 minutes. This orbit allows Landsat 7 to precede the Terra satellite by 30 minutes along a common ground track. The common orbit with Terra offers additional opportunities for data fusion with the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), MISR, and MODIS sensors. The 183-km swath of coverage provided by the ETM+ field-of-view makes it possible to view any given point on the globe once every 16 days.

The ETM+ instrument is an improved version of the Thematic Mapper instruments that flew on Landsat 4 and 5. Like the earlier instruments, ETM+ acquires data for six visible, near-infrared, and shortwave infrared spectral bands at a spatial resolution of 30 m. The ETM+ instrument also incorporates a 15-m-resolution panchromatic band as well as improved ground resolution for the thermal infrared band (60 m vs. 120 m). Incorporation of in-flight full- and partial-aperture solar calibration has improved the overall radiometric accuracy to better than 5%. ETM+ provides imagery that is sufficiently consistent in terms of acquisition geometry, spatial resolution, spectral characteristics, and calibration with previous Landsat imagery to meet requirements for global change research.

A state-of-the-art solid-state recorder capable of storing 380 Gbits of data (100 scenes) is used to store selected scenes from around the world for playback over the U.S. ground station at EROS in Sioux Falls, South Dakota. Data are also routinely downlinked to a station in Australia and forwarded by tape to EROS. Additional U.S. ground stations in Alaska, Svalbard, Norway, and McMurdo, Antarctica are used for special operations. In addition, real-time data from ETM+ are also transmitted to cooperating international ground stations and U.S. ground stations on command.

Landsat 7 Ground Segment

The ground system includes the spacecraft Mission Operations Center built by NASA at Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, and operated by USGS. This Landsat-7-unique facility, augmented by other existing NASA institutional facilities, is utilized to control all spacecraft and instrument operations for the life of the mission. Flight operations are controlled from GSFC with commands uplinked via the Landsat Ground Station in Sioux Falls and via NASA's Tracking and Data Relay Satellite System (TDRSS).

In addition to the Mission Operations Center, NASA built all data processing and distribution components of the Landsat 7 system. These components were integrated into EROS in South Dakota. After launch and on-orbit activation and verification of the satellite and data processing and distribution components, the data processing, archiving, and distribution portions of the ground system were turned over by NASA to USGS for operation. Since then, USGS has re-engineered the ground system to create a multi-mission facility capable of supporting data reception from Landsat 5 and 7, Terra and Earth Observing-1 (EO-1), as well as archiving, processing and distributing products from the entire historical Landsat archive.

In addition to the data reception, processing and archiving functions, NASA and the USGS developed an Image Assessment System (IAS) located at EROS. The IAS continually collects data on the ETM+ radiometric and geometric performance, providing NASA and USGS scientists with a plethora of information and statistics used to monitor the quality and consistency of the data going into the national archive. This capability has been key in Landsat 7's unparalleled achievements in data character-

ization and calibration—hallmarks in the success of the mission.

Landsat 7 scientific data are processed and distributed by EROS. The ground system at EROS is capable of capturing and processing at least 250 Landsat scenes per day to Level 0R (no radiometric calibration, limited geometric correction) and delivering at least 100 scenes to users each day. Scenes are processed to Level 1 (radiometric and geometric corrections applied) at user requests.

Landsat 7 imagery are available for ordering within 24 hours after they are received at EROS. Users query metadata and browse images to determine if the archive contains data files suitable for their use. Data requested can be delivered either electronically or in a digital format on CD-ROM by common carrier.

ETM+

Enhanced Thematic Mapper Plus

An 8-band imaging radiometer aimed at providing high spatial resolution, multispectral images of the sunlit land surface, using visible, near-infrared, shortwave infrared, and thermal infrared wavelength bands, along with a panchromatic band. It is an enhanced version of the Thematic Mapper (TM) onboard earlier Landsat satellites.

Landsat 7 ETM+ Anomaly (May 2003)

The ETM+ sensor performed flawlessly for over four years, acquiring more than 550,000 digital image scenes of Earth's land mass. However, on May 31, 2003 a component of ETM+, known as the scan line corrector (SLC), malfunctioned. By mid-July 2003 the ETM+ resumed its global land survey mission resulting in only a six-week gap of imagery in the U.S. archive. However, the malfunction has had an impact on the imagery from Landsat 7.

The ETM+ optics contain the Scan Mirror and Scan Line Correction Assembly among other components. The Scan Mirror provides the across track motion for the imaging, while the forward velocity of the spacecraft provides the along track motion. The Scan Line Correction Assembly (SLC) is used to remove the 'zig-zag' motion of the imaging field of view produced by the combination of the along and across track motion. Without a functioning SLC, the ETM+ line of sight now traces a zig-zag pattern across the satellite ground track (Fig. 1).

In this SLC-off mode, the ETM+ still acquires approximately 78% of the desired data for any given scene. The gaps in data form alternating wedges that increase in width from the center to the edge of a scene (Fig. 2).

The remainder of the ETM+ sensor, including the scanning mirror, continues to operate, radiometrically and geometrically, at the same high-level of accuracy and precision as it did before the anomaly; therefore, image pixels are still accurately geolocated and calibrated.

The Landsat 7 ETM+ system continues to produce high-quality data of the Earth's land areas. To fulfill the expectations of the user community for full coverage of single scenes, data from multiple acquisitions are being merged to resolve the SLC-off data gaps. The first of these gap-filled products was released from EROS in May 2004. In this Phase I release, the gaps in a current SLC-off scene are filled with data from a SLC-on scene that was acquired approximately one year earlier (i.e., during the same plant phenological stage). The two scenes are geometrically registered, and a histogram-matching technique is applied to the fill pixels that provide the best-expected radiance values for the missing data. The new product represents an effort by the USGS Landsat 7 Project at the EROS Data Center in Sioux Falls, South Dakota to increase the utility of the Landsat 7 ETM+ data affected by the non-functional SLC.

The Phase II release occurred in November 2004 and contained a more advanced product that merged data from multiple SLC-off scenes acquired within weeks of each other. In all cases, a binary bit mask is provided so that the user can determine where the data for any given pixel originated. The USGS is continuing to research other methods of providing better merged data products, and will continue to provide information resulting from this work as it becomes available.

Further information and product samples of the new gap-filled Landsat 7 data can be found at: landsat.usgs.gov/slc_enhancements/gapfilled1.php.

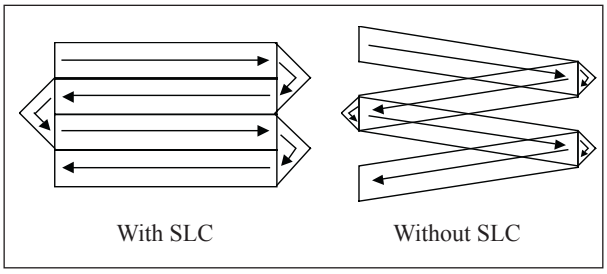


Figure 1

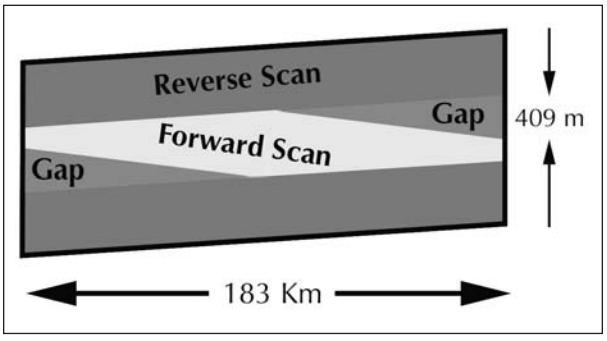


Figure 2

For information on all Landsat data products, visit the Landsat Data Products web site at: landsat.usgs.gov/dataprod.php.

Landsat 7 References

Goward, S. N., and D. L. Williams, 1997: Landsat and Earth systems science: Development of terrestrial monitoring. *Photogram. Eng. Remote Sens.*, **63**, 887–900.

Goward, S. N., and J. G. Masek, eds., 2001: Special issue: Landsat 7. *Remote Sens. Environ.*, **78**, (Issues 1–2).

Landsat 7 Data Products

To search for data, please visit the EarthExplorer or GloVis websites: earthexplorer.usgs.gov and glovis.usgs.gov

Data are no longer available through the EOSDIS Gateway (EDG). Although the method of data access has changed, there are no other changes to the processing or format of the products. Level 1 and Level 0 products that were available through the EDG can now be ordered from the USGS Earth Explorer and the Global Visualization Viewer (GloVis). As before, data processing is done by the Level 1 Product Generation System (LPGS) and National Land Archive Production System (NLAPS). Landsat 5 data cost $425 per scene (for Level 1G processing). Landsat 7 data acquired prior to the SLC malfunction cost $600 per scene (for Level 1G processing). The U.S. Geological Survey (USGS) has reduced the price of Landsat 7 scenes with gaps in data resulting from the SLC failure. Scenes that contain gaps in data have been reduced from $600 to $250. Phase I products, i.e., scenes with the gaps filled using data acquired prior to the anomaly, are also offered at a reduced price of $275 as of May 10, 2004. This product has the gap areas filled in with Landsat 7 data acquired prior to the SLC failure at a similar time of the year. Phase II products, i.e., scenes with the gaps filled using multiple SLC-off images, were made available by the end of 2004 for $300.

Product Name or Grouping	Processing Level	Coverage	Spatial/Temporal Characteristics
ETM+ *Data Set Start Date: June 29, 1999*			
Raw Digital Numbers	0R	233 orbits, each having a 183-km swath width	30 m (bands 1–5, 7), 60 m (band 6), 15 m (band 8) resolution
Calibrated Radiances	1R	183 km × 170 km	30 m (bands 1–5, 7), 60 m (band 6), 15 m (band 8) resolution
Calibrated Radiances	1G	183 km × 170 km	30 m (bands 1–5, 7), 60 m (band 6), 15 m (band 8) resolution
Note: The above data products are described in greater detail in the EOS Data Products Handbook, Volume 2, which can be found at: eospso.gsfc.nasa.gov/eos_homepage/for_scientists/data_products/vol2.php.			

Landsat 7 Data Products